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HIGH SPEED MULTIWAVELENGTH OPTO-ELECTRONIC SOURCES, MODULATORS AND DETECTOR ARRAYS

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13. ABSTRACT *(Maximum 200 words)*
In this effort, novel techniques based on semiconductor traveling wave optical amplifiers were demonstrated. These devices provide potential solutions to the challenges in wavelength-division multiplexing - time-division multiplexing (WDM-TDM) networks and millimeter wave communication systems. The semiconductor traveling wave optical amplifier provides a self-stabilized source of multiple optical wavelengths for WDM and low phase noise millimeter-wave and terahertz signals for wireless telecommunications and TDM. A single-stripe semiconductor traveling wave amplifier (STWA) was fabricated that demonstrated four-wavelength, 10-Gbit/sec picosecond pulse generation. The advantages of this approach include self-stabilization and "sharing" a common RF and DC driving source among each wavelength channel. This effort also investigated ultrafast optical pulse generation using intracavity heterodyning of multiple phase-locked wavelengths and also simulated the temporal modulation generated within the multiwavelength laser.

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I. Introduction

The explosive growth of telecommunications and computer communications has placed an increasing demand on the national and global communications infrastructure. There is a worldwide effort to find new technologies that will support our future networking needs.

Optical fibers offer an extremely wide channel for data transmission. The low loss window around 1.55μm in silica fibers has a bandwidth of roughly 20THz. The passband of erbium-doped fiber amplifiers (EDFAs) is narrower but still on the order of 4THz. Presently, current lightwave systems exploit only a small fraction of the potential bandwidth. Mining this vast bandwidth is important in order to support future advanced network services and the information superhighway.

One approach to exploit the fiber bandwidth is through the technique of time-division multiplexing, which has been the traditional electronic approach in telephone and data communications. In TDM, the individual bits representing data are made as short as necessary in order to assemble all the bits into a single data stream. The term multiplexing conveys that although the data rates of any particular user may be far less than the total system bandwidth, data from a group of users is assembled together or multiplexed into a single data stream with a high aggregate data rate. Recent experiments have demonstrated point-to-point transmission of optical TDM bit streams at 100Gbit/sec rates, which translates into an optical bit every ten picoseconds [1]. The main challenges of this technology are the need for ultrahigh-speed devices operating at extremely high rates and the need to maintain very precise synchronism in a geographically distributed network.

Currently, alternative research efforts are underway, examining the benefits and trade-offs of wavelength-division multiplexed networks. In wavelength-division multiplexing, the spectrum is divided into separate wavelength channels, each operating at bit rates up to several Gbits/sec. Compared to TDM, this relaxes the need for individual device operation and synchronization at ultrahigh speeds. WDM can be designed to directly exploit the tremendous bandwidth of optical fiber and transmit moderate data rates in parallel to obtain aggregate terabit data transmission. In order to implement WDM optical networks, various fixed wavelength and wavelength tunable components are required. One issue of interest is the need for a multiplicity of laser sources to provide the different wavelengths required for the WDM channels. The challenge exists in the need to closely stabilize the wavelengths of multiple, independent and geographically separated laser sources.

In wireless communications, more recent attention has focused on the generation and transmission of mm-wave signals on optical carriers, as a result of the allocation of mm-wave frequencies for wireless links to overcome crowding in the lower frequency spectrum, and of precise phase controls for millimeter waves. Mobile and personal radio systems at such frequencies also offer the advantages of smaller equipment and antennas. The challenges remain to develop optical techniques for simple, reliable and low phase noise mm-wave signal generation.

In this project, we have demonstrated novel techniques based on semiconductor traveling wave optical amplifiers to provide potential solutions to the challenges in WDM-TDM networks and millimeter wave communications. In particular, we have experimentally investigated and characterized novel multiwavelength, high speed optical pulse generation methods capable of

(1). providing self-stabilized sources of multiple optical wavelength for WDM networks;

(2). providing low phase noise mm-wave and terahertz signals for wireless telecommunications and TDM networks.

The key component in our approach is the semiconductor traveling wave optical amplifier. The intrinsic wide bandwidth, capability of high speed modulation and mode locking, high gain, reliability and compactness make semiconductor devices important for optical telecommunication networks.

II. Background

i. Multiwavelength optical signal generation

Several research groups have recently demonstrated dual-wavelength and multiwavelength optical signal generation[2-7]. Morioka *et al* generated more than 40 WDM channels over 1530-1570nm at 6.3Gbit/sec from a single laser source utilizing laser-diode-pumped supercontinuum in optical fiber[2]. Weiner *et al* first mentioned the possibility of applying pulse shaping to dense WDM [3] and Nuss *et al* confirmed the feasibility of this approach by passing femtosecond pulses from a Ti:sapphire laser through a pulse shaper containing a SEED array for amplitude modulation at 622Mbit/sec[4]. Most recently, Boivin *et al* demonstrated a 206-channel wavelength division multiplexed transmitter using a single femtosecond laser at 1.55 μm and a single modulator. The channel spacing is 0.3 nm and the bit rate of each channel is 36.7 MHz[5]. The advantage of these systems is obviously the large capacity of phase locked

WDM wavelength channels, while the disadvantages are the complexities involved in the generation of femtosecond optical pulses, the inevitable loss incorporated when filtering or multiplexing different wavelength channels, the lack of wavelength tunablity, and the low channel data rate.

For semiconductor laser based devices, recent efforts have focused on the use of semiconductor laser arrays, in which strong gain competition associated with single-stripe device is avoided. Burn *et al* demonstrated a dual-wavelength external-cavity semiconductor laser based on two intracavity gratings, which in turn limits incorporating more wavelengths[6]. Zhu *et al* showed dual-wavelength picosecond optical pulse generation using an actively mode-locked multichannel grating cavity[7]. This work demonstrated the promise of individually addressing each WDM channel with less gain competition between each WDM channel. However, owing to utilizing an individual ridge stripe, the synchronization or phase correlation between each WDM channel is deteriorated. Other remaining drawbacks are the elaborate fabrication and packaging of multiple ridge stripes and obvious lack of wavelength tunablity. Wang *et al* demonstrated a novel tunable dual-wavelength operation of a diode array with an external grating-loaded cavity[8]. It provides a variety of wavelength tunablity and phase correlation between two wavelength channels.

Thus far, there has been no demonstration of semiconductor laser sources with more than two wavelengths, primarily owing to the gain competition mechanism in the diode lasers. Most available multiwavelength laser systems utilize multiple DFB lasers with each tuned to a different wavelength, separated by channel spacings. The need to closely stabilize the wavelengths of multiple, independent and geographically separated laser sources is currently also considered a difficult challenge.

ii. Optical generation of multigigahertz and multiterahertz signals

Optical generation of multigigahertz and multiterahertz signals using currently available optical sources is not straightforward. At present, state-of-the-art semiconductor lasers exhibit less than 30 GHz modulation bandwidth although the addition of an external cavity enables narrowband modulation beyond the resonant frequency [9-10]. External modulation has been reported up to 75 GHz[11] but most commercially available devices are limited to around 30GHz.

The main techniques that are currently being investigated to overcome these limitations include optical heterodyning, harmonic generation, and resonant enhancement of the semiconductor laser response. Optical heterodyning offers the prospect of high power levels, but normally involves two discrete semiconductor lasers and the

requirement for relatively complex feedback systems to control the phase correlation of the generated signals. Harmonic generation by using either laser nonlinearities, an external modulator or pulsed semiconductors is inefficient since the power is usually distributed over a large number of harmonics and only one harmonic is selected. Resonant enhancement of laser diodes requires a mm-wave synthesizer at the frequency of interest, and the device must be capable of responding to this frequency.

Recently Wake *et al*, Novak *et al*, and Wang *et al* have reported similar dual-mode self-heterodyning techniques. Wake *et al* uses a dual-mode DFB semiconductor laser in cw operation (they are not clear why they can generate two-mode behavior with a range of mode spacings)[12]. Since the laser is running cw, the phase of optical modes is not correlated, and electrical subharmonic injection is used to lock the phase. This approach can not continuously vary the beating frequency and additional phase locking circuitry is needed. Novak *et al* solved the phase locking by using two modes from an actively modelocked semiconductor laser[13]. Nevertheless, the linewidth of modelocked diode laser limits the beating range, and filtering out all other modes will reduce the output power. Beat frequencies as high as 7THz was made by Wang *et al* with less than 20% modulation depth, by using two cw wavelengths selected by an intracavity filter[14]. The lack of phase correlation contributes to the poor depth of modulation and high beat signal phase noise. Most recently, research by N. Onodera demonstrated THz optical beat frequency generation by *two* independent modelocked semiconductor lasers driven by a common source, and discussed a proportional relation between beat frequency and modulation depth[15]. By using optical pulses in the beat frequency generation process, this approach can reduce phase fluctuations of each laser.

Since all these techniques use only two optical modes, the resulting beat signal is of sinusoidal form. Multiple phase-locked modes have not been reported to self-heterodyne and generate an ultrashort beat *pulse* signal, which is not only beneficial to the mm-wave technology but also to the terahertz optical TDM networks.

III. Experimental Results obtain in this Program

i. Four-wavelength, 10-Gbit/sec picosecond pulses generation from a single-stripe semiconductor traveling wave amplifier

Motivated by the demand of self-stabilized sources of multiple wavelengths for WDM networks, we investigated the possibility of using single-stripe semiconductor traveling wave amplifiers (STWA) for multiwavelength generation. Single-stripe

semiconductor lasers have been thought as unfeasible for simultaneous multiwavelength operation owing to the strong gain competition between the oscillating modes. With novel designs, we demonstrated a tunable four-WDM-channel modelocked laser suitable for WDM-TDM networks, based on a single-stripe STWA. By active harmonic modelocking the grating-loaded external cavity laser system at 2.5 GHz, stable pulses have been generated at four wavelengths simultaneously. Pulsewidths of ~18 ps have been generated for the composite four-wavelength output, and for each individual wavelength output. The advantages of single-angled-stripe diode lasers over diode laser arrays for multiwavelength generation lie in the potential for enhanced phase correlation between each wavelength, high pumping efficiency, ease of facet anti-reflection requirements, better transverse mode for coupling into optical fibers, and simplicity.

Figure 1 schematically shows the setup of the four wavelength laser. Actively modelocked optical pulses are generated from the laser diode by incorporating an intracavity spectral filter to define the individual spectral components. The end mirror M2 reflects the four selected spectral components back to the gain device to complete the four wavelength channel generation. A collinear composite four-wavelength pulse train is coupled out from the zeroth order grating reflection. Modelocking is made by injecting ~1W rf sinusoidal signal at a frequency of 2.5GHz with 175mA of dc bias current into the diode chip.

Figure 2 illustrates the output four wavelength spectra in active modelocking (upper) and in cw operation (lower). Stable four wavelength lasing was demonstrated at a pulse repetition rate of 600 MHz, 2.1 GHz, and 2.5 GHz. In comparison, gain competition prevents the stable operation of the laser in a multiwavelength cw mode.

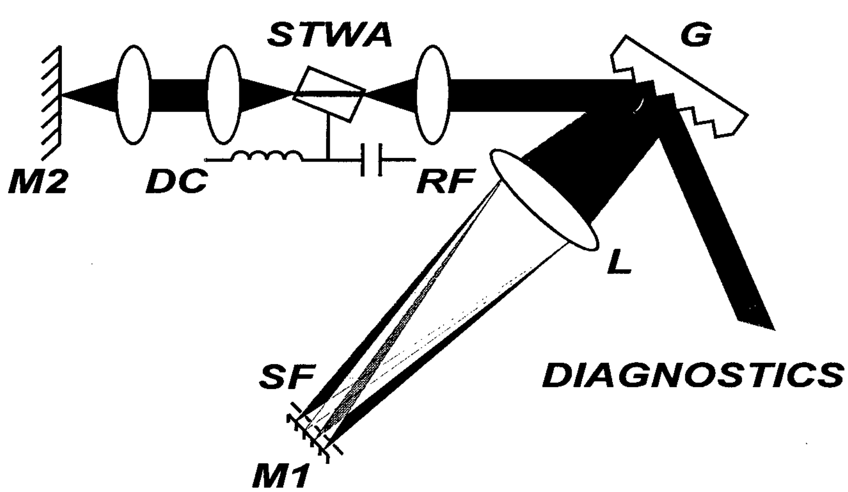

Fig.1. Schematic of the experiment setup. STWA--single-angled-stripe semiconductor traveling wave amplifier; G--grating (1800 line/mm); SF--spatial filter; L--150mm achromatic lens; M--end mirrors.

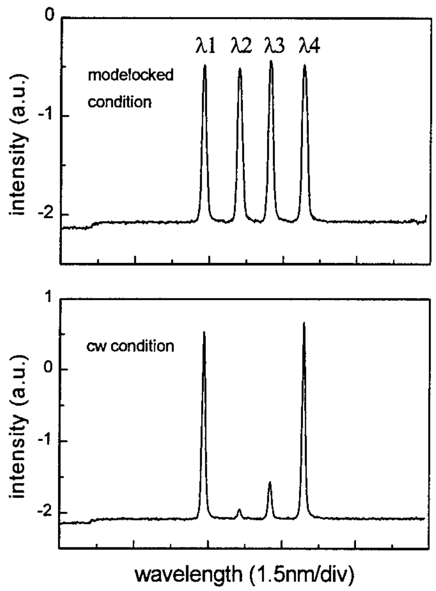

Fig.2 Output spectra of four wavelengths

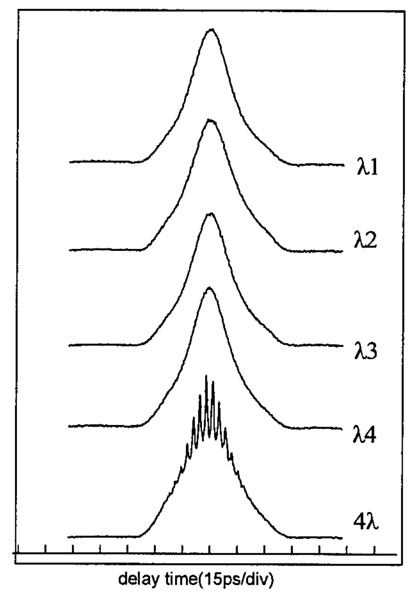

Fig.3 Autocorrelation traces of output pulses

In Figure 3 are autocorrelation traces of the composite four-wavelength output and of each individual wavelength component. It is observed from these data that the temporal profiles of the pulses are identical and synchronized, with a deconvolved pulsewidth of 18 ps. The peaks impressed on the composite four-wavelength pulse show a correlated phase relation between each wavelength channel, where the temporal modulation is proportional to the wavelength separation between each channel.

Figure 4(a) shows the tuning characteristic of the composite four wavelength output, with a fixed spectral separation of ~1nm, and tuned over the gain bandwidth of the STWA (>20nm). Figure 4(a) suggests that as many as 19 wavelengths separated by 1nm could be supported from this device. In Figure 4(b), the tuning characteristic is shown where the individual wavelength separation is varied from ~0.8nm to ~2nm. Notice that in both cases, the spectral intensities decrease with large detuning, showing the influence of the gain spectrum of the STWA.

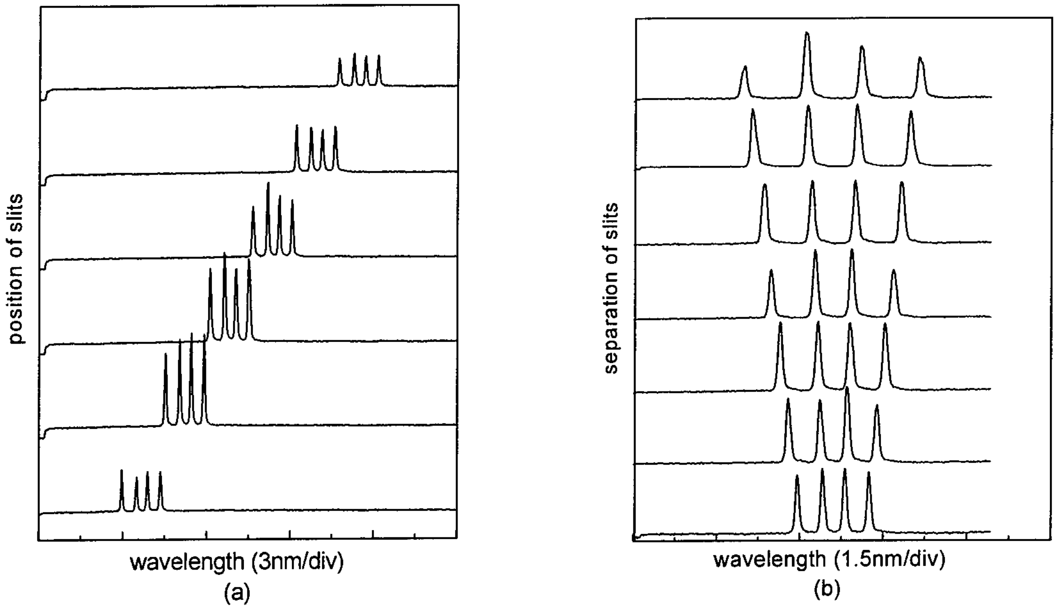

Fig.4. Tuning of the four wavelength spectra.

In cw single-stripe diode lasers, the competition of lasing wavelengths is quite strong, making simultaneous multiwavelength output difficult to maintain, even though dual wavelengths were reported based on the theory of spatial hole-burning and spatially separated gain media in a diode array [3]. We believe that the success of four wavelength generation from the single-stripe diode laser contributes to exploiting the transient unsaturated gain from an actively modelocked laser. Under modelocked operation, the gain of the single-stripe device is periodically depleted by the actively modelocked pulses inside the cavity. The pulse width is typically tens of picoseconds for active modelocking and the pulse period ranges from several hundred picoseconds to a few nanoseconds, depending on modelocking rate. After the depletion of the gain by an optical pulse, the gain partially recovers prior to the arrival of the second pulse. During this period, unlike that in the free running of diode laser, the device will experience an unsaturated gain which will provide gain over a broader spectral region and thus reduce the competition between multiwavelength components.

The advantages of this approach include 1) its self-stabilization since all wavelengths are derived from a single modelocked laser, 2) correlated relative timing jitter between wavelengths since each wavelength channel shares a common rf and dc driving source and a common cavity, i.e., all wavelengths simultaneously experience the same cavity perturbation, and 4) the approximately equal net gain carried on each WDM

wavelength since each wavelength component is generated within the same gain region. The two modes of wavelength tunability is certainly another feature of this approach.

This portion of work has been reported at the IEEE/LEOS and OSA jointed 1997 Spring Topical Meeting of "Ultrafast Electronics and Optoelectronics" in Nevada[16].

ii. Investigation of ultrafast optical pulse generation using intracavity heterodyning of multiple phase-locked wavelengths

The ultrafast temporal modulation on the composite four-wavelength pulse suggests that a correlated phase relation exists between the individual wavelength components in the multiwavelength laser. In this case, it is possible to exploit and generate highly phase-locked multigigahertz and terahertz optical pulse trains with very low timing jitter.

We start from intracavity self-heterodyning of *two* optical frequencies. By using a two-slit intracavity spatial filter, we can allow two wavelengths to simultaneously oscillate. The output average power directly from the oscillator is ~0.6mW, by injecting 160mA dc and 500mW rf to the oscillator diode. By amplifying the light with a secondary semiconductor traveling wave amplifier, which is biased by 225mA dc and ~700mW rf, the amplified average power reaches 30mW. A home-built interferometric autocorrelator is utilized to analyze the dual-wavelength pulse train after the optical amplifier. The interferometric autocorrelation will be capable of providing us with pulse *chirp* information, as compared with the intensity autocorrelation, in which only the pulse shape can be observed. The harmonic modelocking frequency is set at ~600MHz, which is the second harmonic of the fundamental. This frequency is selected because higher harmonics will increase the pulse number inside the cavity and reduce the modelocking efficiency. We also observed that using the fundamental frequency brought in satellite pulses around the primary modelocked pulses, which is believed to be gain amplification of pulses between the diode and the nearest end mirror.

By using interferometric autocorrelation techniques, we investigated the effect of an intracavity spatial filter on the intrinsic chirped pulse, and the effect of pulse chirp on the beating phenomena.

Figure 5 illustrates the intracavity filter design. The slits are designed in a fan pattern to implement convenient wavelength tuning. By moving the slits vertically relative to the spectrum, one can adjust the wavelength separation. By translating the slits horizontally relative to the spectrum, one can vary the center wavelength of each channel at any fixed specific wavelength separation. The slit width is made around 0.1mm, which

acts like a spectral filter with the appropriate bandwidth to suppress the residual F-P modes (0.3nm separation for 350μm long diode chip) from the incomplete AR coating of our diode chip.

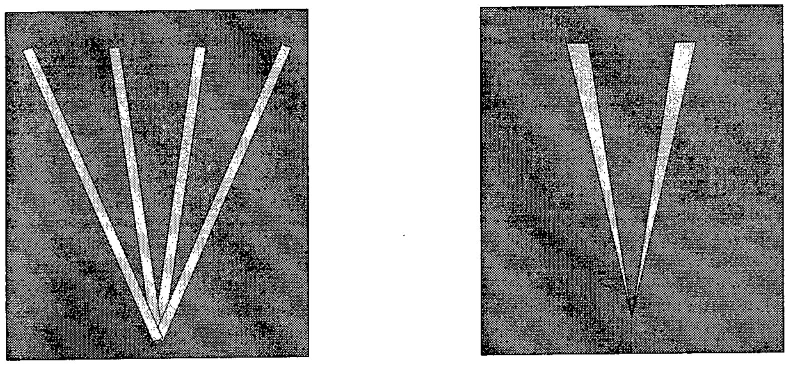

Fig.5. Filter designs for four-wavelength laser (left), and dual wavelength laser (right)

If one of the two slits in Figure 5 (right) is blocked, the autocorrelation will show one clean pulse. This is illustrated in Figure 6a, and displays a single chirped pulse, an intrinsic phenomena of actively modelocked diode lasers. However, if we narrow the slit and the pulse spectrum, by moving the slit upward, a nearly transform-limited pulse is generated, as shown in Figure 6b. This is a typical pulse shaping effect, primarily owing to the suppression of self-phase-modulation(SPM) occurring in the diode. Notice that the autocorrelation traces are on different time scales in order to show both long range and fine details of the interferometric autocorrelation.

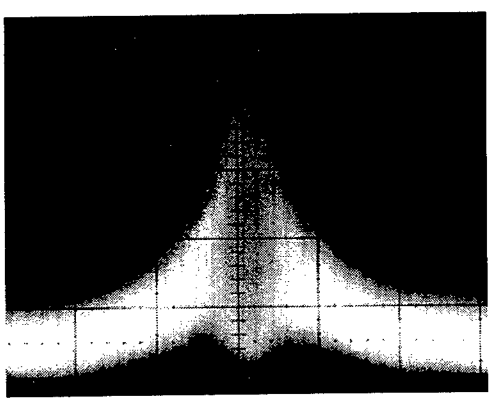

Fig.6a. Time scale: 20ps/div. Intrinsic chirped pulse.

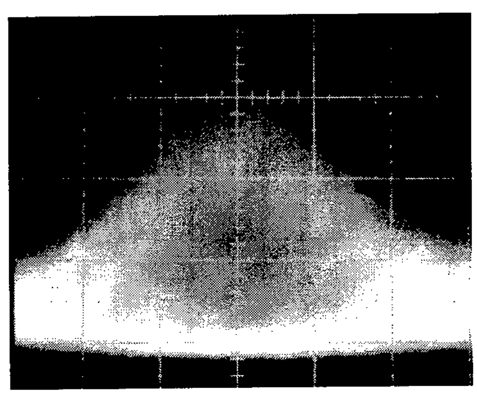

Fig.6b. Time scale: 8ps/div. A nearly transform-limited pulse after spectral filtering.

It should be noted that the multiwavelength wavelengths are apparently excited by statistically independent noise sources in different designated portions of the spontaneous

emission spectrum of the diode laser. External rf current modulation results in the locking of modes *within* each wavelength cluster. Phases of modes that belong to different wavelength cluster are distributed randomly. However, since the pulses belonging to different wavelength cluster both spatially and temporally overlap, they will simultaneously experience the same SPM induced chirping process. Questions remain why multiple apparent phase-unlocked wavelengths consistently beat with each other, and what effect the chirping mechanism will play in the temporal beating process.

To address the primary issue of the fundamental mechanism for initiating a phase correlation between each wavelength channel, it is believed that the ultrafast beating will modulate the gain at frequencies equivalent to the multiple wavelength separation, and provide phase locking between multiple wavelength clusters. Initially, at some instant, some or all of the modes across multiwavelength spectrum will be in phase. When this happens, it will generate a temporal beat within the optical pulse intensity that will modulate the gain medium with a modulation frequency on the order of wavelength separation. This ultrahigh-speed periodic gain modulation initiates the locking of phases between the wavelength components so that stable beating can be maintained, similar to the function of an rf modulation signal in a conventional actively modelocked diode laser. A novel real time pump-probe time-resolved gain measurement is underway to confirm this assumption.

Figure 7 illustrates an interferometric autocorrelation trace of the dual-wavelength output, showing the temporal modulation impressed on a single wavelength pulse envelop. It can be seen that the single wavelength pulse is chirped from the descending wings while the temporal modulation shows a quasi-transform-limited, high contrast autocorrelation signature. This suggests that the chirp between the two separate wavelength are similar and phase correlated. Considering that the multiple wavelength pulses spatially and temporally overlap, any unmatched chirp will make the beat frequencies vary from point to point across the pulse, and make the autocorrelation lose contrast. We observed in our experiments that the modulation patterns possess a large depth of modulation and are steady across an approximately 80ps temporal range, more than twice the pulse FWHM. These preliminary results suggest the existence of a strong wide-band phase locking mechanism to coherently couple the independent multiwavelength output.

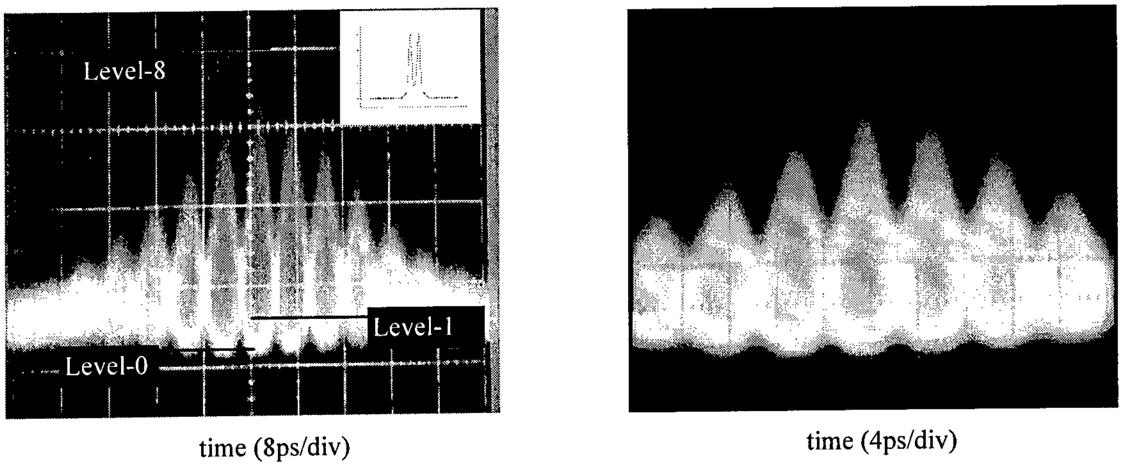

Fig.7. Dual wavelength beating signals. The descending wings suggest that single wavelength pulse is chirped. The inset shows dual-wavelength spectrum with separation ~0.4nm, corresponding to 167GHz beating frequency. Right picture is a close-up and shows the 167GHz in frequency. Notice that the poor photosensitivity of Polaroid does not record the whole interferometric pattern.

Furthermore, walk-off between the individual pulses at each specific wavelength may change the relative chirp matching, which will reduce the temporal overlap, *and beating*. The walk-off, in this case, is attributed to a group velocity delay by the pulse compressor portion of multiwavelength laser cavity (Figure 1). In the dual-wavelength experiment, the walk-off effect is not observed by translating the achromat and filter-end-mirror configuration toward or away from the grating owing to the two closely spaced wavelength (0.3~0.4nm) components in order to obtain the temporal modulation.

In conclusion, we have discussed the phase locking mechanism which locks multiple wavelengths and supports low phase noise temporal modulation. Equal chirp across temporally overlapped multiwavelength pulses does not deteriorate the modulation, however, temporal walk-off between the multiwavelength pulses will reduce the depth of modulation. Since the self-heterodyning of wavelengths occurs within the laser cavity and the multiple wavelengths are selected geometrically external to the diode chip, our approach will solve the low beat signal power problem and excel in maintaining constant wavelength spacing. Actively modelocking the system will provide strong stability in the simultaneous multiwavelength operation. Further investigations are planned for examining the multiwavelength temporal modulation, which is a distinct feature in addition to the multiwavelength laser operation.

iii. Numerical simulation of the temporal modulation generated within the multiwavelength laser and its effect on the depth of modulation

Through computer modeling, we have obtained a fundamental understanding of

(1). how the chirp induced by self-phase-modulation effects the multiwavelength self-heterodyning process; and

(2). how group velocity dispersion effects the beating effect.

In the simulation, we use the linewidth and wavelength spacing obtained from the experiment. Since the observed lineshape is close to Gaussian, we adopt it into the program. Sufficient sampling bandwidth (6.38THz or 15nm) and sampling points (2048 points) are used to avoid aliasing. Four figures are illustrated: spectral intensity, spectral phase or group delay, temporal intensity, and intensity autocorrelation, for each case.

Figure 8 shows four wavelengths with a flat spectral phase. The intensity autocorrelation shows a transform-limited pulsewidth (envelope) with a 100% depth of modulation.

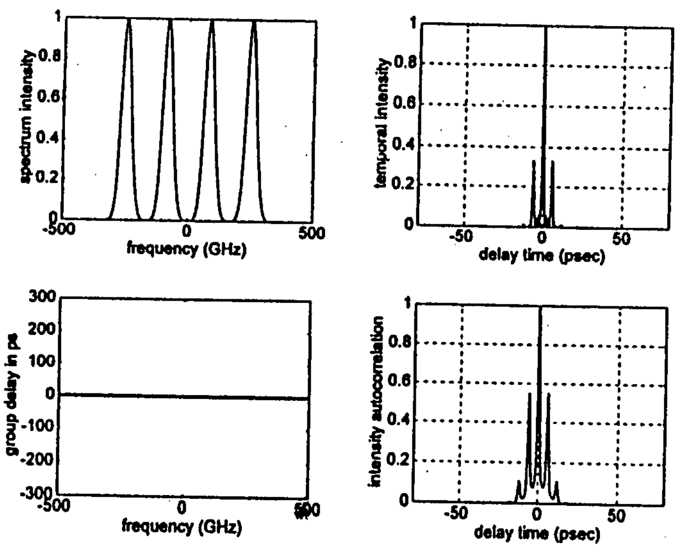

Fig.8 Flat-phase chirp-free multiwavelength beating process

Before proceeding, an additional concept needs to be defined in the simulation. Chirp is referred to a nonlinear process usually addressed in time domain. By definition, the temporal derivative of phase is called chirp. When a pulse is chirped by a nonlinear optical process, the pulsewidth remains constant while the pulse spectrum is changed. Group delay, on the other hand, is a linear process usually addressed in frequency domain. By definition, the frequency derivative of spectral phase is called group delay.

When a pulse experiences group-delay, the spectrum remains constant, while the pulse width is changed. In an actively modelocked diode laser, if one looks at a non-transform-limited pulse *at one instant*, there is not enough information to tell whether this pulse is chirped or is group-delayed from a transform-limited shape. The point we want to make here is that we will use spectral phase to simulate grating induced *group delay* as well as *chirp* in special cases without losing generality of the chirp effect.

Figure 9 illustrates the case when the four wavelength pulses are equally linearly 'chirped', a possible case if the individual wavelength pulses temporally and spatially overlap. Here we can use linear group delay to represent linear chirp as long as the group delay length, thus pulsewidth, is kept the same for all four wavelengths. It can be seen that equal chirps have no effect on temporal modulation. From this, it is obvious that each pulse is broadened, which gives a wider envelop than that shown in Figure 8.

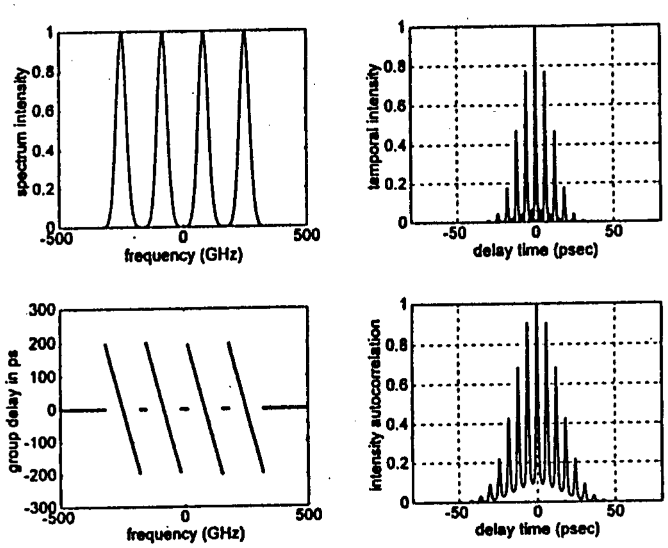

Fig.9 Equally linearly chirped multiwavelength beating process.

In a similar manner, Figure 10 shows how different chirp affects the temporal modulation. For simplicity and without losing generality, chirp with relative opposite signs are chosen. It can be seen that in only a narrow central region of the pulse, where the difference of the chirp is small, the large depth of modulation is maintained. This phenomena is enhanced graphically from a dual-wavelength situation and is shown in Figure 11.

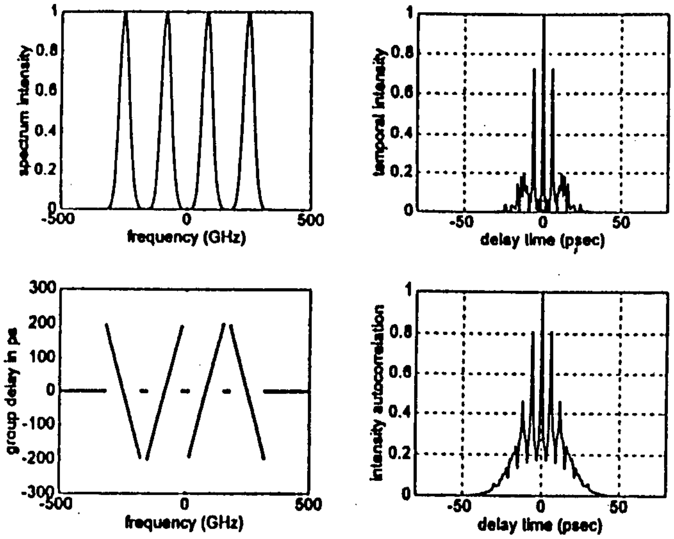

Fig.10 Independently chirped *multiwavelength* beating process.

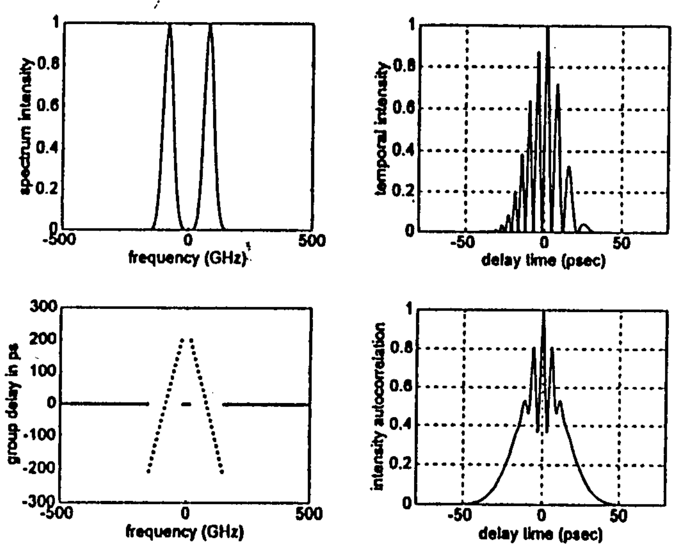

Fig.11 Independently chirped *dual-wavelength* beating process.

The walk-off effect is illustrated in Figure 12 and Figure 13. In both cases, the same small amount of linear group delay across multiple wavelengths is introduced simulating the intracavity grating, which is kept small enough as not to obviously change the pulse envelop. A dramatic difference can be observed between the two and four wavelength cases. The insensitivity of dual wavelength beating to grating effects agrees with the experiment observation (notice that the optimum dual-wavelength beating yields ~67% modulation depth in the intensity autocorrelation trace).

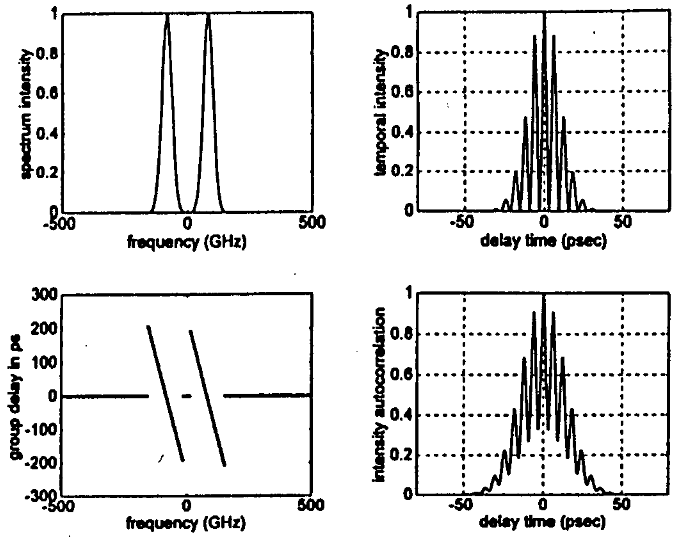

Fig.12 Walk-off effect on *dual-wavelength* beating process.

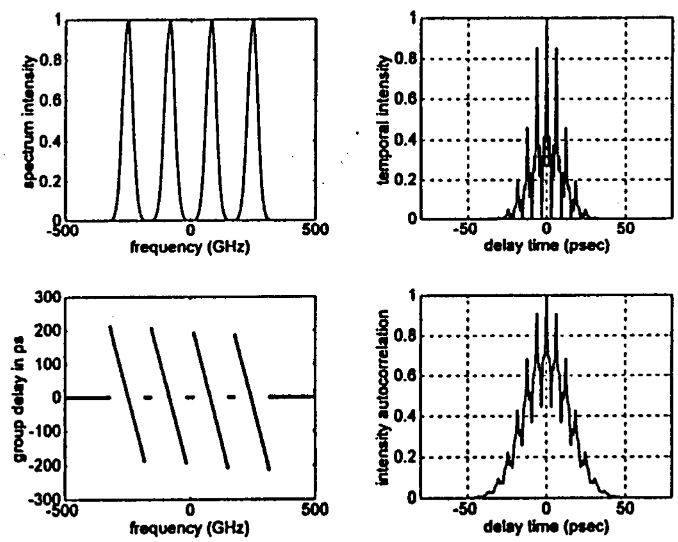

Fig.13 Walk-off effect on *multiwavelength* beating process.

Another potential source of degradation of the depth of modulation in the experiment is the non-uniform wavelength channel spacings owing to the available spatial filter design. This is simulated in Figure 14 and Figure 15. In Figure 15, the grating effect is added. From this, it is clear that the non-uniform spacing deteriorates the beating effect and the grating effect makes this even worse.

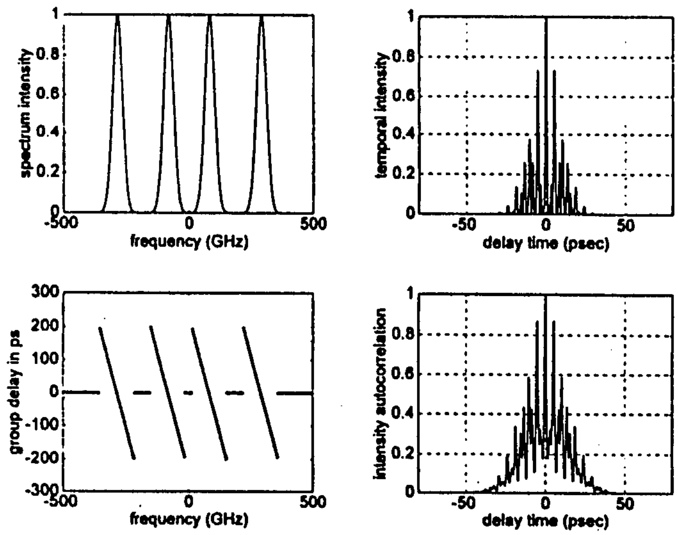

Fig.14 Multiwavelength beating under non-uniform wavelength spacing only.

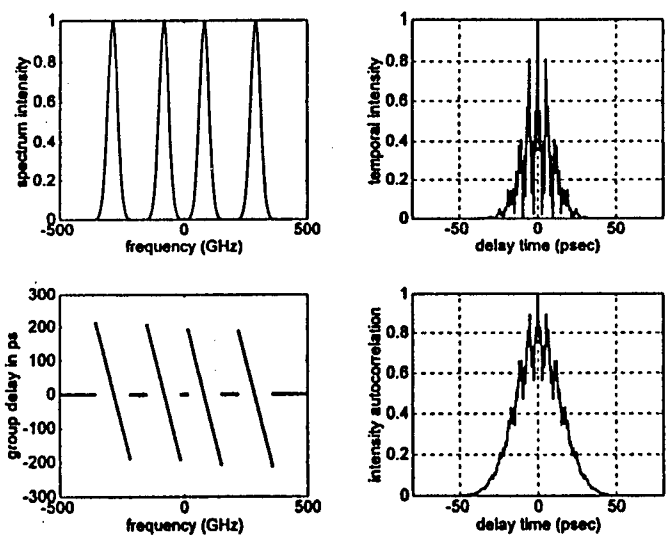

Fig.15 Multiwavelength beating under non-uniform wavelength spacing *plus walk-off.*

We end up this section with one comparison. Figure 16 shows a comparison between an experimentally obtained intensity autocorrelation of the composite four-wavelength output and a simulated result, including the effects contributing to the reduction of the temporal modulation depth, i.e., the intracavity grating group delay and the non-uniform wavelength spacing.

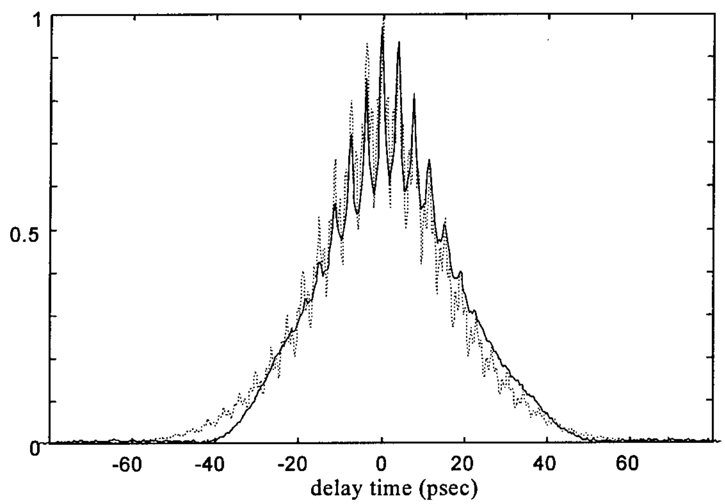

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Fig.16 Comparison for intracavity grating (walk-off) *and* non-uniform spacing effect on multiwavelength beating process. Dot line is the simulation curve, solid line is the experiment autocorrelation trace.

IV. Future Work

A completely detailed investigation and characterization is underway to fully understand the mechanism of multiwavelength oscillation and wide-band phase correlation in semiconductor traveling wave optical amplifiers. A real-time pump-probe time-resolved gain measurement will be conducted to observe the gain response to high speed temporal modulation owing to multiwavelength self-heterodyning. The result will help us to reveal wide bandwidth phase locking problem.

As we suggested before, low relative timing jitter, or low relative phase noise instead, between multiple wavelength channels is an important feature for our single-stripe diode based multiwavelength modelocked laser. To demonstrate this we plan to perform a single sideband (SSB) phase noise measurement for each channel relative to rf driving signal source. We expect that under the deterioration of the timing of the overall output pulse, random timing jitter between each channel will still be correlated.

Complete simulation of the multiwavelength laser will be developed to include chirping effects from time domain, and group delay from frequency domain. This work will provide insight into the overall device performance.

An eight-wavelength, 5Gbit/sec per channel semiconductor laser is also planned, using quantum well semiconductor optical amplifiers, which will allow the generation of an aggregate data rate up to 40 Gbit/sec.

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